A state-wide groundwater recharge estimate for South Dakota and the Black Hills

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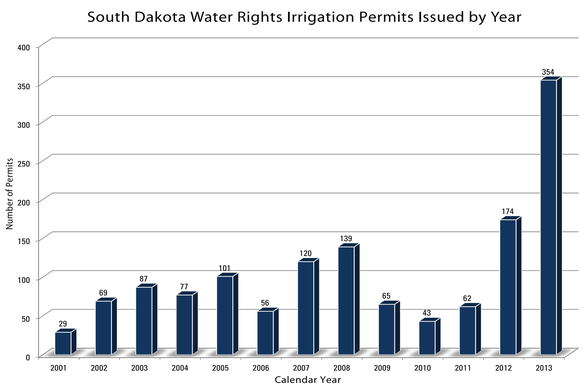
USGS science for a changing world

Abstract

Rapidly increasing demand for groundwater in South Dakota requires a better understanding of groundwater availability. For this reason the U.S. Geological Survey (USGS) South Dakota Water Science Center, in cooperation with the National Park Service, the Black Hills National Forest, and the West Dakota Water Development District, began a computer modeling project for groundwater flow in Black Hills aquifers. The model will help assess the effects of current or future groundwater extraction or drought on regional groundwater availability. Aquifer recharge from precipitation is one of many inputs for this groundwater model. Using the USGS Soil-Water-Balance (SWB) model, groundwater recharge from precipitation for the entire State of South Dakota and the Black Hills area in eastern Wyoming was calculated. The SWB model uses a modified Thornthwaite-Mather soil-water-balance method to calculate spatially distributed recharge values for rectangular grid cells. The recharge value for each grid cell is the difference between the change in soil moisture and the sources and sinks over a daily time step. The model calculates soil moisture using intermediary values including precipitation minus potential evapotranspiration, accumulated potential water loss, actual evapotranspiration, and soil-moisture surplus and deficits. Model inputs included daily precipitation and air temperature, land cover, hydrologic soil group, available soil-water capacity, and hydrologic run-off flow direction data. Recharge values for the study area were calculated at a 1-kilometer (km) spatial resolution for calendar years 1981 to 2011. The estimated 30-year average recharge for the study area ranged from more than 8 inches per year (in/yr) in some parts of the Black Hills to less than 0.1 in/yr in southwestern South Dakota. To determine the average annual recharge to the Madison and Minnelusa aquifers, which are important groundwater resources in western South Dakota, the study area was overlain with the lateral extents of the recharge areas, which included overlying surficial deposits. Using this method, the estimated 30-year average recharge from precipitation to the Madison and Minnelusa aquifers was calculated as 3.11 and 2.17 in/yr, respectively. The SWB model routes excess water in each cell to down-slope cells that can accept this routed water as recharge if the soil is not fully saturated. This function, however, was not used because it causes large inaccuracies in a model with a resolution as coarse as 1 km. The sensitivity of this flow-routing function on estimated recharge values was tested by using high-resolution (30-meter) models.

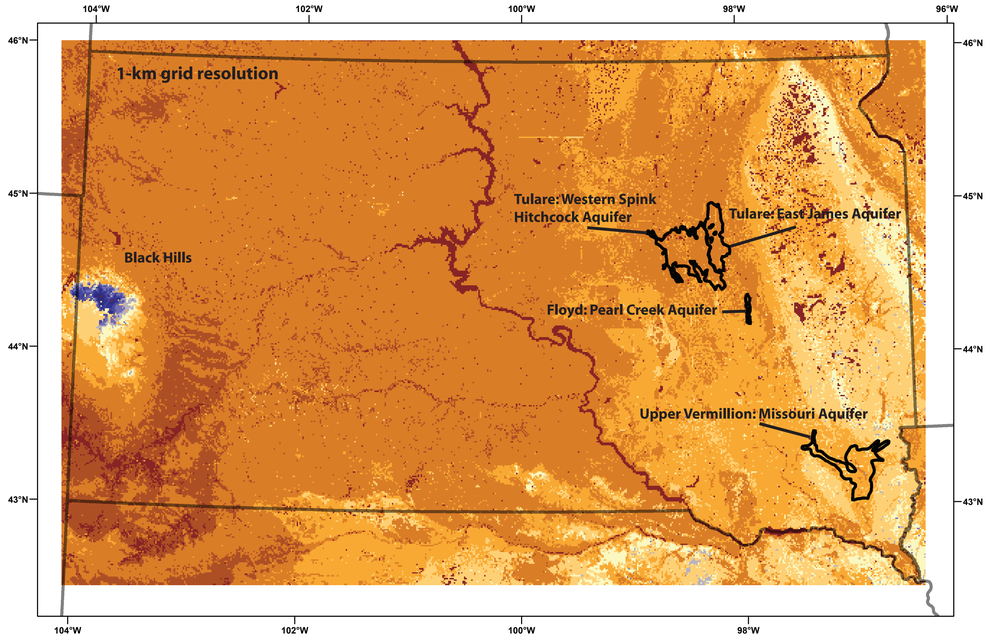
Increasing groundwater demand in South Dakota



- Irrigation water permits issued by the South Dakota Water Rights Program increased 100% from 2012 to 2013
- Before approving an irrigation permit, the state must show that aquifer recharge exceeds withdrawal
- Soil-Water Balance modeling can assist with this calculation

From Ken Buhler, SDDENR, personal communication (2014)

Average annual recharge for South Dakota



- Model used climate data from 1981 to 2011
- Highest 30-year average annual recharge is over 8 in/yr in the Black Hills region
- Lowest average annual recharge is less than .1 in/yr in southwestern South Dakota

0 50 100 MILES
0 60 120 KILOMETERS

Explanation

Avg Annual Recharge (in)

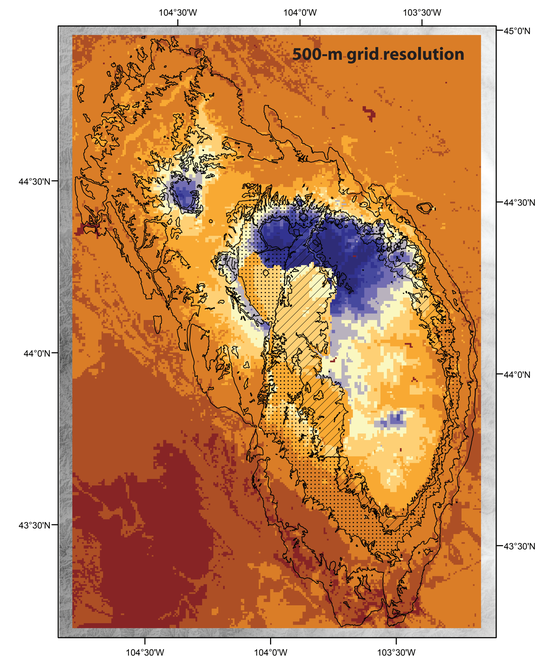
- < .01
- 0.01 - 0.1
- 0.11 - 1
- 1.1 - 2
- 2.1 - 3
- 3.1 - 4
- 4.1 - 5
- 5.1 - 6
- 6.1 - 7
- 7.1 - 8
- > 8.0

- Aquifers shown are either approaching or are already fully allocated for groundwater withdrawals
- SWB model differs from the water budget calculation because SWB estimates recharge only from precipitation to the land above the aquifer

Aquifer	Water Budget Calculation Method		Soil Water Balance Computer Model	
	Data Years	Average Annual Recharge (inches)	Data Years	Average Annual Recharge (inches)
Tulare: Western Spink Hitchcock	2003-2012	.83	1981-2011	.72
Tulare: East James	1980-2011	.76	1981-2011	.55
Upper Vermillion: Missouri	1980-2011	.25	1981-2011	1.71
Floyd: Pearl Creek	1979-2011	.22 - .90	1981-2011	.99

Modified from Ken Buhler, SDDENR, personal communication (2014)

Average annual recharge for the Black Hills



Explanation

- Madison Outcropings
- Minnelusa Outcropings
- Inyan Kara Outcropings

Avg Annual Recharge (in)

- < .01
- 0.01 - 0.1
- 0.11 - 1
- 1.1 - 2
- 2.1 - 3
- 3.1 - 4
- 4.1 - 5
- 5.1 - 6
- 6.1 - 7
- 7.1 - 8
- > 8.0

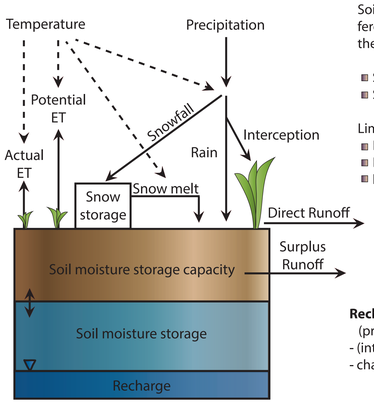
0 10 20 MILES
0 10 20 KILOMETERS

- Black Hills model used climate data from 1981 to 2011
- Highest 30-year average annual recharge is over 8 in/yr in northern Black Hills
- Lowest values are less than .1 in/yr in southwestern areas

Aquifer	Yield Efficiency Calculation Method		Soil Water Balance Computer Model	
	Data Years	Average Annual Recharge (inches)	Data Years	Average Annual Recharge (inches)
Madison	1950-1998	3.90	1981-2011	3.11
Minnelusa	1950-1998	2.77	1981-2011	2.17
Inyan Kara	-	-	1981-2011	.78

Modified from Carter and others (2001)

Soil-Water Balance (SWB) theory



Soil-Water Balance calculates recharge as the difference between the change in soil moisture and the flow rates of sources and sinks.

- Sources: precipitation, snowmelt, inflow
- Sinks: interception, outflow, evapotranspiration

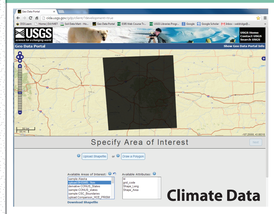
Limits of the method include:

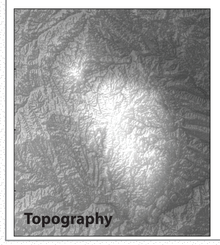
- Rainfall intensity not considered
- Evapotranspiration only from min/max temp
- Interpolated climate data

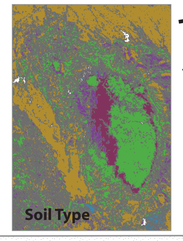
Recharge =
(precipitation + snowmelt + water inflow)
- (interception + outflow + evapotranspiration)
- change in soil moisture

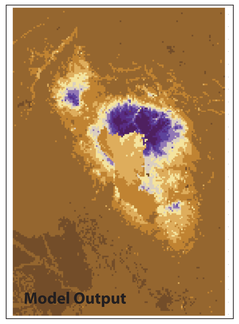
Modified from Aurand (2013)

Soil-Water Balance modeling









Soil-Water Balance model inputs include:

- Climate data: temperature and precipitation
- Elevation data/flow routing information
- Soil type
- Land cover/runoff curve number

Conclusions

Picture courtesy South Dakota Department of Environment and Natural Resources

- SWB modeled recharge values for South Dakota range from .1 in/yr to over 8 in/yr
- Highest modeled recharge rates occur in the Black Hills
- Lowest modeled recharge rates occur in southwestern areas of the state
- Model correlates well for unconfined aquifers in western South Dakota but does not correlate as well for confined aquifers in eastern South Dakota

Future work

- Construct groundwater models for the Madison and Minnelusa aquifers of the Black Hills using SWB data
- Complete groundwater models for Powder River and Williston basin areas
- Determine methods to predict and correct SWB's flow routing inaccuracies
- Model soil moisture levels and compare them to field data
- Explore the impact of climate change on aquifer recharge rates

Selected references

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